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MANAGEMENT SCIENCE AND THE DEVELOPMENT OF POLICIES: AN APPLICATION IN MANPOWER PLANNING

By

Christoph Haehling von Lanzenauer *
Richard Horwitz **
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I. INTRODUCTION

For many years, problems of manpower management have received much attention both in the academic and managerial literature. [7] While the focus of analysis was for some time on demand analysis and manpower statistics, the interest has shifted more recently towards decision and policy making. This trend results from development of management science concepts which allow formulating complex manpower problems accounting for the interdependencies of decisions such as recruiting, selecting and hiring, training and career development, job assignments, the effects of learning, motivation and compensation and relating these decisions to internal (budget, financial, marketing) and external (competition, economic factors , legal aspects) conditions. [1,4] The ability of computers to solve large scale models efficiently made practical applications possible.

The purpose of this paper is to present the development of a long term manpower plan in an insurance company setting. Such a manpower plan can be expressed by very specific decisions which are to be implemented at given points in time or as a set of policies on which will determine what decisions are to be made under prevailing conditions. While the interpretation of a plan by lower management is in terms of specific decisions and activities, senior management looks at a plan more from a policy point of view. The latter approach has the distinct advantage of being more general. Specific decisions can be determined from such policies typically under a wide range of internal and/or external conditions. This is not the case for the former as the dynamics of the situation frequently require the decision variables to be redetermined. Unfortunately, this less flexible orientation in applying management science to managerial problems has been prevailing in the past. We will take the latter perspective and demonstrate the effective use of management science concepts to senior management problems.

II. COMPANY BACKGROUND

Effective manpower management is of key importance to organizations operating with a large sales force. In reviewing its manpower decisions, management of an insurance company began evaluating its current practices and searching for ways of improving the decision making process in

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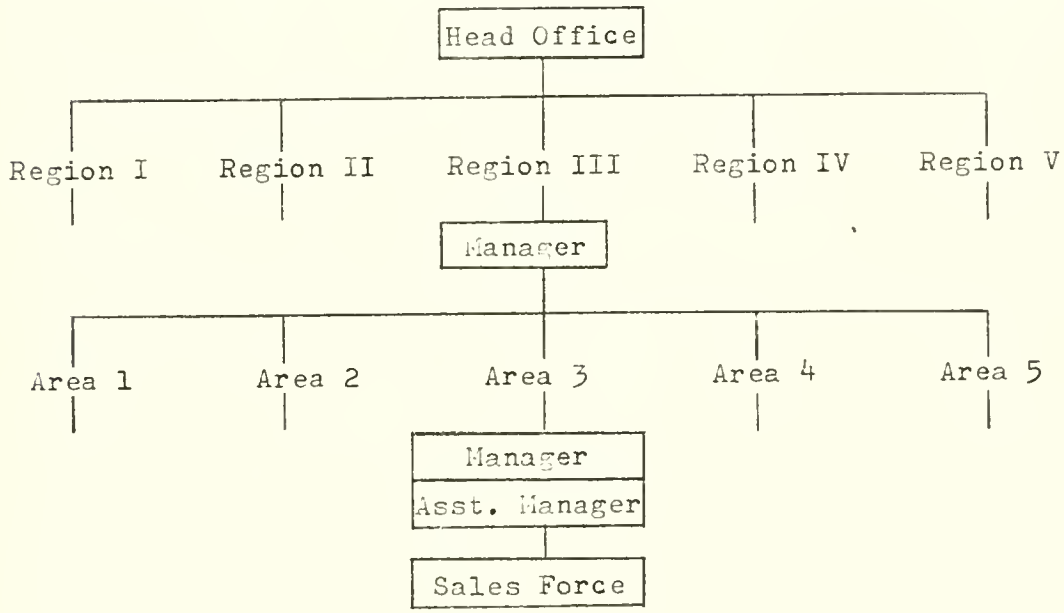
this area. More specifically, the review concentrated on assessing current hiring and training practices and revealed a need for replacing piecemeal decisions by a comprehensive plan [3, 6].

The company was organized by five geographic regions which in turn were broken down into five areas. (Exhibit I).

Exhibit I

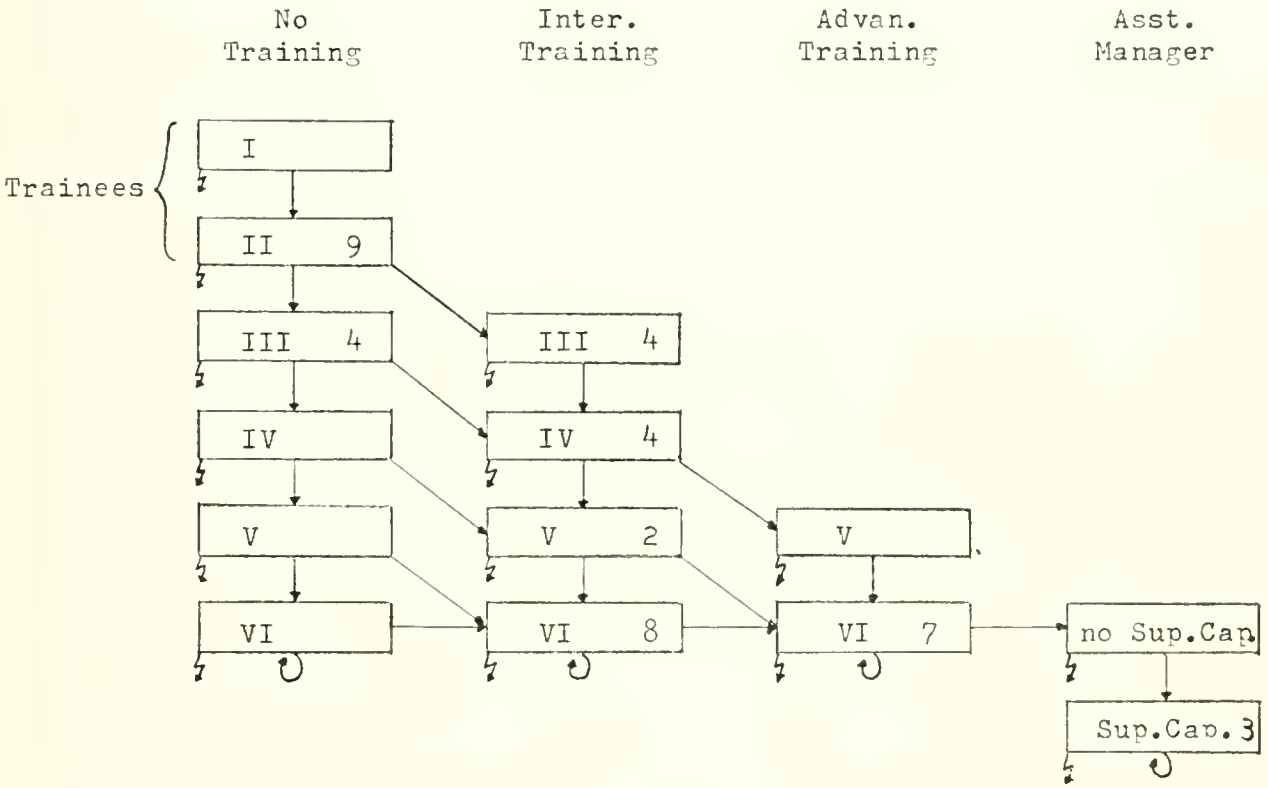
Organizational Structure



The sales force was composed of salesmen who were classified according to the length of service with the company (Groups I through IV) and the training status they had obtained. Exhibit II summarizes the hierarchical structure and indicates the number of people in each group prior to the beginning of the planning horizon for one region.

Exhibit II

Hierarchical Structure and Strength of Sales Force



↯ indicates attrition

Each region was responsible for its own recruiting, hiring and training decisions, although training activities were developed, organized and run at the corporate level. The development of hiring and training policies could therefore be restricted to the regional level.

III. ELEMENTS OF THE PROBLEM

In developing policies for manpower planning one must identify the alternatives available to the policy maker and evaluate these alternatives in light of the company's short and long term objectives while accounting for internal (organization,capacity) and external (market, competition) constraints. The complexity of the task becomes obvious from Exhibit II indicating that management must decide periodically - here every six months - on:

(a) The number of new salesmen to be hired. It should be noted that laying off people must not be explicitly considered as salesmen are on a commission basis.

(b) The number to be sent to the intermediate course.

(c) The number to be sent to the advanced course.

(d) The number of assistant managers to be developed. The only source for assistant managers are group VI men with advanced training. An additional dimension would be to allow assistant managers to be developed from internal as well as external sources.

The development of policies must not only be made on a multiperiod basis to reflect the sequential character of the problem but also account for the internal and external restrictions:

(a) Organizational considerations require trainees (new salesmen) to be supervised during their first two periods with the company. Each area manager and assistant manager can supervise at most two men.

(b) Besides the area manager at most one assistant manager is permitted per area,thus limiting the number of assistant managers for the region considered to five.

(c) An assistant manager can begin supervising trainees after a six-month period in the position.

(d) The total sales force (not including managers and assistant managers) for the entire region is limited to a managerial determined maximum which reflects both market potential and competitive pressures.

(e) Only eligible salesmen can attend the respective training programs. Eligibility is defined as having spent at least two periods since attending the last training program.

(f) Attrition of personnel of course must be accounted for. This aspect complicates the analysis as attrition cannot be predicted with full accuracy and thus an element of uncertainty enters into the problem.

Although the problem is restricted as outlined above, there still exists a large number of different solutions defined as sets of values for the policy variables which satisfy the restrictions. This necessitates the use of a criterion (such as minimizing cost, maximizing contribution to profit and overhead) for comparison and selection purposes. The definition of a criterion is a most important step in the analysis as it determines which of the feasible solutions should be selected as the optimal one. The step requires understanding and interpretation of corporate goals as well as insights into what aspect of a subsystem contributes to the organization's overall objective of profitability.

Ignoring the subsystems Underwriting, Claims and Investment of the company, we consider only the cost and benefits effected by the policies of the subsystem sales . For the problem under consideration, cost result from hiring and training decisions and a commitment for subsidies and salaries for trainees and assistant managers, while benefits materialize from higher sales due to more and better trained salesmen and from lower attrition rate. Exhibit III summarizes the cost to be considered.

Exhibit III

Summary of Cost

Hiring	Fixed Cost	$1,000
	Var. Cost/Hiree	100
Int. Training	Fixed Cost	4,000
	Var. Cost/Participant	240
	Loss in Income while being trained /Participant	190
Adv. Training	Fixed Cost	5,000
	Var. Cost/Participant	300
	Loss in Income while being trained /Participant	260
Asst. Manager	Development cost/man	1,500
	Salary/man/period	3,000
Trainee	Subsidy/man /period	1,500

Higher sales will produce additional premium income over the lifetime of a policy sold. Because of differences in the life of insurance policies, the first year premium income (after commission) is used as a proxy to measure a salesman's productivity. Based on company records, it is possible to determine these average productivity figures for the different groups of the sales force (Exhibit IV). It should be noted that assistant managers continue to sell about 75% of the volume of a group VI man who has completed the advanced training program. According to management the productivity figures remain valid as long as the total sales force does not increase by more than one man every two periods. Exhibit IV also contains information on attrition rates for the various groups. As future productivity figures and attrition rates are uncertain, the information in Exhibit IV represents estimates.

Exhibit IV

Summary of Productivity Figures and Attrition Rates

Group	No Training	Intermediate Training	Advanced Training	Assistant Managers
I	$ 3,084			
	30%			
II	3,780			
	25%			
III	4,470	$ 4,710		
	25%	20%		
IV	5,040	5,310		
	24%	15%		
V	5,700	5,972	$ 6,312	
	22%	15%	7%	
VI	6,180	6,450	6,720	$ 5,400
	19%	11%	7%	15%

The criterion as a basis for comparing alternative policies for manpower planning can cow be expressed as the difference between the first year premium income and the controllable costs. While the cost in each period can be attributed directly to the hiring and training activities, the benefits resulting from the decisions in a given period will continue for some time into the future. This phenomenon necessitates the analysis of the problem over a planning horizon of T periods.

IV. MODEL DEVELOPMENT

Due to the many interrelated aspects and the multiperiod character of the problem, policies for manpower planning can best be developed by a mathematical model which allows one to consider simultaneously the many variables and their interactions with the constraints and to select the best policy for a given criterion.

A number of questions, however, should be addressed before the process of building a model is undertaken. The key question is "What is a model to be used for?". The model was intended to improve certain manpower decisions. It was not the objective to determine a set of values for the decision variables, rather than to provide those in control with policy guidelines for making manpower decisions. This policy orientation has important implications for the model builder; it means that the formulation of a model for the entire region could be in aggregate terms and should not account explicitly for every detail at the area level. The aggregate form simplifies the model as fewer variables are needed. The resulting policies can then be applied at the area level to arrive at disaggregate decisions.

The dynamic nature of the problem makes it necessary to evaluate the criterion over some planning horizon of T (T=1, 2,...) periods. The use of a finite horizon is frequently criticized as it tends "to drive the sales force into the ground" at the end of the planning horizon. To avoid this one could include additional restrictions close to the end of the horizon to insure minimum hiring and training activities. This not only complicates the formulation, but also undermines the purpose of the model as policies are presumed in the model rather than determined by the model. A more practical

way is to handle this aspect by utilizing the concept of a rolling planning horizon. This implies that only the results for the first k(k=1, 2,...) periods of the planning horizon will be implemented. After k periods have been added to keep the planning horizon equal to T periods, the model is then used again. This approach also provides the answer to the fundamental question in planning: How long to plan into the future or what value should T have? Without going into any detail we state that one should keep increasing the length of the planning horizon, as long as an additional period changes the optimal policies for the first k periods which will be implemented. More formally, the optimal planning horizon T* is

$$T^* = \min \{T\} \qquad T = k, k+1, \ldots$$

s.t.

$$X^k(T) = X^k(T+1) = X^k(T+2) \ldots \qquad (k=1, 2,\ldots)$$

with $X^k(T)$ being a vector of optimal policies or decisions for the first k periods as a function of the length of the planning horizon. This definition assumes that the value for k is externally determined, frequently on the basis of budgetary considerations.

Of course the longer the planning horizon the more uncertain will be the internal and external information entering the model. This raises the issue of formulating the problem in deterministic or probabilistic terms. While a probabilistic model is generally a closer representation of reality, it does not necessarily produce better results. Again, the determining factor for this choice should be the use of the model. For the problem under consideration where policies are to be developed which determine what decisions to take under existing conditions, a deterministic model proves to be appropriate as shown in section VI.

V. FORMULATION

Based on the above discussion, a mathematical model for a region in aggregate terms is suggested. This involves relating the decision variables to each other, to the internal and external restrictions and to the criterion. With the exception of the hiring and training decision all variables are

defined at the end of a period after attrition has taken its toll. The model can be represented by the following relationships:

Supervision Constraint:

Since salesmen during their first two periods require supervision, we must insure that the number to be supervised does not exceed the supervision capacity. Thus, we have for every period t(t=1, 2, ..., T) of the planning horizon

$$\begin{array}{l}\text{Salesmen hired in period } t \\ + \text{ men in group I at end of } t-1\end{array} \leq 10 + 2 * \begin{array}{l}\text{Assistant managers capable} \\ \text{of supervision in } t\end{array}$$

As attrition takes place randomly throughout a period, the formulation guarantees that the supervision aspect is not violated at any point in time. The 10 in the right hand side results from the five area managers each capable of supervising two trainees.

Assistant Manager Constraint:

In every period t we must insure that the total number of assistant managers is less than five. Thus

$$\begin{array}{l}\text{Assistant managers without supervision capacity in } t \\ + \text{ Assistant managers with supervision capacity in } t\end{array} \leq 5$$

Total Sales Force Constraint:

Due to the limited growth potential and the fact that the productivity figures in Exhibit IV are only valid over certain ranges, the total sales force in every period must be less than or equal to an upper limit. The upper limit increases by one man every second period to reflect limited growth. Although assistant managers contribute to the sales volume, they are not included in the sales force. Thus we have for every t

Salesmen hired in t
+ men without training in all groups at t-1
+ men with intermediate training in all groups at t-1
+ men with advanced training in all groups at t-1
$\leq$ upper limit in t

The formulation insures that sales force constraint is met at any point throughout a period.

Eligibility Constraints:

Of course not more men than eligible can be sent to the respective training programs or be developed as assistant managers. For every period t we have

Men sent to the intermediate course in t $\leq$ Men without training in groups II, III, IV, V and VI at the end of t-1.

Men sent to advanced training during t $\leq$ Men with intermediate course in groups IV, V and VI at the end of t-1,

Men developed as assistant managers in t $\leq$ Men with advanced courses in groups VI at the end of t-1.

Balance Restrictions:

The manpower balance equations are the key to most manpower problems. They determine the number of people in a given classification at t by adding to the number of people in the same classification at t-1 to the flow into the given classification and subtracting the flow out of the same classification. The concept is illustrated for one classification:

Men with itermediate training in group V at t = (Men with intermediate training in group IV at t-1
+ Men in group IV at t-1 who take intermediate course in t
- men with intermediate training in group IV who take advanced course in t) * (1 - attrition rate of men in group V with intermediate training)

The formulation implies that attrition in any period takes its toll after any training took place. These balance equations must be derived for all classifications.

Objective Function:

Finally, we must define the criterion by determining the benefits and cost as a function of the decision or policy variables over the planning horizon. Thus we have:

$$E = \sum_t [\text{First year premium income of all salesmen and assistant managers in } t$$
- fixed and variable hiring cost in t
- fixed and variable training cost in t
- loss in premium income due to participating in training programs in t
- salaries for assistant managers in t
- subsidies for trainees in t]

First year premium income for each period is simply determined as the product of the productivity rate from Exhibit IV multiplied by the respective number of men in each group of the end of period t. Similarly, variable hiring and training cost, loss in premium income due to taking a training course, subsidies for the trainees and salaries for the assistant managers are determined by multiplying the respective cost figure with the number of hirees, trainees, and assistant managers. The fixed hiring and training cost however create some problems as they are independent of the number hired and trained. Thus,

$$\text{Fixed hiring cost} = \begin{cases} \$1000 & \text{if number of hirees} \geq 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Fixed training cost} = \begin{cases} \$4000 & \text{if men attend the intermediate course} \\ 5000 & \text{if men attend the advanced course} \\ 0 & \text{otherwise} \end{cases}$$

The task is then to determine the policy which maximizes E subject to the various restrictions.

VI. SOLUTION PROCEDURE AND RESULTS

Finding a solution to the problem as formulated can be done in a number of ways.

1. Man-Machine Interaction

The idea behind this approach is to combine human creativity and judgement with the ability of the computer to rapidly and accurately perform calculations and to evaluate logic relationships [2]. Using this approach a human decision maker selects a value for the length of the planning horizon, develops a policy and translates this policy into values of the decision variables. These values are then period by period entered into a computer which based on a program representing the formulation, checks whether the various restrictions are met. If a constraint is violated, (e.g., the policy might call for more new salesmen to be hired than is possible with the current supervision capacity), the computer informs the decision maker of that condition and requests a new set of input variables. If the values for the decision variables are consistent with the restrictions, the computer evaluates the corresponding revenues and costs and determines the value of the objective function for the chosen planning horizon. This information, along with the size and composition of the sales force is made available to the decision maker who after evaluation of the results may select a different policy at which the cycle begins again.

Exhibit V illustrates for a planning horizon of T=10 periods the results[1] of the following policy:

(a) Hiring as many new salesmen every period as possible,
(b) Sending every odd period all eligible people to the intermediate course provided at least four men attend (if less than four people are eligible, the intermediate training is postponed for two periods),
(c) Sending every even period all eligible people to the advanced course, provided at least five people attend (as above, advanced training is postponed for two periods if less than five people are eligible),
(d) Developing an assistant manager if less than two assistant managers are in the system.

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(1) Since the attrition aspect in the manpower balance equations can produce fractional men, the results are rounded to the nearest integer number. The fractional result however is used in the next period in order to preserve the attrition rates as given in Exhibit IV.

EXHIBIT V

Results: Man Machine Interaction

Period t	Hirees	At beginning of t		Number eligible for			Number trained			At end of t		Maximum
		Sales Force*	Asst. Mgrs.	Int. Course	Adv. Course	Asst. Mgrs.	Int. Course	Adv. Course	Asst. Mgrs.	Sales Force	Asst. Mgrs.	Sales Force
1	8	46	3	13	14	7	13	-	-	39	3	46
2	7	46	3	0	19	7	-	19	-	40	2	46
3	7	47	2	5	6	24	5	-	-	40	2	47
4	7	47	2	3	5	23	-	5	-	40	2	47
5	8	48	2	6	3	26	6	-	-	41	1	48
6	7	48	1	4	5	24	-	5	1	39	2	48
7	9	48	2	7	2	25	7	-	-	40	2	49
8	8	48	2	3	5	23	-	5	-	42	1	49
9	6	48	1	7	3	26	7	-	1	39	2	50
10	10	49	2	4	3	24	-	-	-	42	2	50

* After hiring but before attrition

Inspecting the results indicates that hiring activities under this policy are limited throughout the entire planning horizon by the maximum sales force constraint. The hiring activities in conjunction with the training programs, however, are not sufficient to take advantage of the growth potential. Furthermore, it appears that "training in groups" is effective for controlling fixed training costs, but it is not obvious whether this one-dimenstional point of view - keeping the cost of training down - is for the better of the company as a whole as the benefits resulting from training programs will be limited. Only evaluating other policies will provide a better understanding of these tradeoffs.

Insights into the problem structure, however, reveal that an extremely large number of different policies do in fact exist. Of course, only a few can be evaluated and typically, the policy maker discontinues his search if a satisfactory policy has been developed. Naturally, there is no guarantee that the "best" policy found, is the best policy that exists. Although the concept of man-machine interactions provides a better understanding of the complex problem and is capable of developing sound policies, the approach satisfies this rather than optimizes the policy maker's criterion; this is a serious shortcoming.

2. Mathematical Programming

The manpower problem formulated can be summarized as a problem in which an objective function is to be maximized by selecting values for the decision variables subject to a set of constraints. Thus, the problem can be cast in the general framework of mathematical programming. Mathematical programming is a methodology by which an optimal solution is mathematically derived and guaranteed. Using mathematical programming, first the set of values for the decision variables which maximizes the objective function without violating any restriction is determined and these optimal decision variables are then translated into policies for manpower decision making.

From the nature of the problem, it is not meaningful to hire or train fractional men. This implies that all decision variables in the mathematical programming approach should be in integer format. Furthermore, since the

fixed hiring and training cost occur only if people are hired and trained but are independent of how many, it is necessary to relate these fixed costs to zero-one variables. Thus, an all integer programming version appears to be appropriate. Without considering the possibility of laying off salesmen and/or assistant managers and a planning horizon of T=10 periods, the integer programming version requires about 250 decision variables and 270 constraints.

The difficulties and cost associated with solving larger integer programming problems make the approach somewhat impractical [5]. At this point, one should recall the purpose of the model: The model is to be used to develop policies for the hiring and training activities rather than to produce detailed decisions. Thus, with the exception of the few zero-one variables relating to the fixed cost, it is not critical whether or not the remaining decision variables are integer. This implies that the model can be represented by linear programming with some zero-one variables (mixed integer linear programming). The model has been solved using IBM's MPSX-MIP system.(2) Exhibit VI summarizes the optimal solution for a planning horizon.

As the purpose of the model is to develop manpower policies, the results must be translated into policy statements. By inspecting and interpreting the results from the mathematical program the following policies can be derived:

(a) Hiring Policy
In any period hire as many new salesmen as possible in light of the total sales force and/or the supervision constraint.

(b) Training Policy - Intermediate Course
Including period 9 train as soon as salesmen become eligible provided the number trained is four or greater.

(c) Training Policy - Advanced Course
Including period 7 train as soon as possible provided the number eligible is 2 or greater.

(d) Development Policy - Assistant Managers
Do not develop any assistant managers during the entire planning horizon.

---

(2) The calculations were carried out in MIT's Information Processing Center.

EXHIBIT VI

Results: Mathematical Programming

Period t	Hirees	At beginning of t*		Number trained in Int. Course		Number trained in Adv. Course		Asst. Mgr. Devel.	At end of t		Maximum Sales Force
		Sales Force	Asst. Mgrs.	GroupII	GroupIII	GroupIV	GroupV		Sales Force	Asst. Mgrs.	
1	8.00	46.00	3.00	9.00	4.00	4.00	10.00	-	39.13	2.55	46
2	6.87	46.00	2.55	-	-	6.80	-	-	39.62	2.17	46
3	7.38	47.00	2.17	4.20	-	6.12	-	-	40.60	1.84	47
4	6.40	47.00	1.84	-	-	-	-	-	40.39	1.57	47
5	7.61	48.00	1.57	3.88	2.71	2.86	-	-	41.36	1.33	48
6	6.64	48.00	1.33	-	-	2.30	-	-	41.30	1.13	48
7	7.62	48.92	1.13	4.00	2.52	2.64	-	-	42.19	.96	49
8	6.59	48.78	.90	-	-	-	-	-	41.83	.82	49
9	7.02	48.85	.82	4.00	2.61	-	-	-	41.96	.69	50
10	6.48	48.44	.69	-	-	-	-	-	36.93	.59	50

* After hiring t but before attrition

Some discussion of these policies and the general approach is warranted:

Hiring: The hiring activities are limited by the total sales force restriction (external constraint) during periods 1 through 6 and the supervision restriction (internal constraint) during periods 7 to 10. Information as to the binding constraints is useful for managerial decision making as internal and to some extent also external constraints can be modified, which is in fact the essence of long range capacity planning. In the context of this problem, however, the policy indicates that expanding the supervision capacity is not recommended. It is interesting to note that hiring activities are carried out at the maximum level up to the end of the planning horizon. There is no "driving the salesforce into the ground" phenomenon. The fixed hiring costs are not high enough to warrant any grouping in the hiring process.

Training: Intermediate training is not recommended during the last period, and no advanced training should be carried out during the last three periods, although the number eligible is greater than four or two respectively. This phenomenon is clearly a result of using a finite planning horizon, but it has no implications for the policies during the first k periods if $k << T$. Although the priniciple of training in groups applies to both programs, it materializes only for the intermediate course. The asymmetry of the policies - a higher threshold for the intermediate course although the fixed cost is lower - is not a priori obvious but results in part from the different benefits to be derived from the training programs, specifically the lower attrition after advanced training. The larger reduction in the attrition rates of the advanced training compared with intermediate training might imply that the advanced training course is the more "productive" one. However, there will be no advanced training unless salesmen took the intermediate course. In short, the various aspects of the problem are highly interrelated and must simultaneously be accounted for, a task being done best by mathematical programming.

Finally, lacking a sufficient number of eligible men, there should be no intermediate training in certain periods. From an organizational point of view, however, it might be desirable to train in every period. The objective function for such a policy would decrease by about .02% (2/100 of one percent). This implies that the threshold determined is very insensitive.

Assistant Managers: The policy of not developing assistant managers might imply that assistant managers are wasteful. This is not the case as can be seen by reducing the number of assistant managers initially available to one. The

corresponding policy is to develop assistant managers such that one assistant manager capable of supervising trainees is available. The results, however, indicate that three assistant managers are certainly not needed for supervision purposes. It is interesting to note that assistant managers are developed from group VI men with advanced training. This of course causes some cannabalization as these men are most profitable to the company. Evaluating the alternative of developing assistant managers from the outside indicates that assistant managers would be developed only from the outside at a level as dictated by the total sales force constraint.(3)

General Approach: The derivation of policies using mathematical programming is always possible as the policy variables are determined by some binding constraints and the economic forces of play. The translation of the decision variables in to policies is, however, not easy and requires careful interpretation of the output from the mathematical programming system. Identification of binding constraints should be emphasized as they represent the concern of senior decision-makers in long range capacity planning.

The policies are derived using expected or average attrition sales. If the actual attrition differs from what is expected, the policies derived still provide the basis for decision making, although the resulting decisions may change. This is the reason why a deterministic version of the model is appropriate for the aspect attrition which is probabilistic.

Finally, the issue of the length of the planning horizon must be addressed. The results presented in Exhibit VI are based on a planning horizon of T=10 periods. Whether T=10 is too short or too long depends on the nature of the problem and the value selected for k, the number of periods for which the policies are to be implemented without rerunning the model. Because of the numerous interactions of the various aspects of the problem, an answer can only be obtained experimentally. For k=2, a planning horizon of T=8 periods is optimal while for k=3 the planning horizon has to have 10 periods.

---

(3) In evaluating this alternative it was necessary to include all assistant managers into the total sales force as the result would be trivial otherwise (i.e., hire assistant managers from the outside at such a level that number of assistant managers is equal to five). This is furthermore meaningful as assistant managers sell 75% of the volume of a group VI man with advanced training.

As such an experimental evaluation is very costly, understanding the nature of the problem and insights into its structure should form a basis for selecting a reasonable value of T. In the context of this problem with k=2 T=10 was an adequate choice.

VII. CONCLUSION

The purpose of this paper was to discuss the development of a manpower planning system in an insurance company setting. The policy orientation which reflects senior management involvement had significant implications for model formulation and solution procedure. Although the concept of man-machine interaction provides useful insights and can produce sound policies, only mathematical programming will yield optimal results. The policies derived using mathematical programming indicate that intuitive decision making is likely to fail in complex and highly interrelated problems and proves that Management Science has something to offer in addressing problems of concern to senior management.

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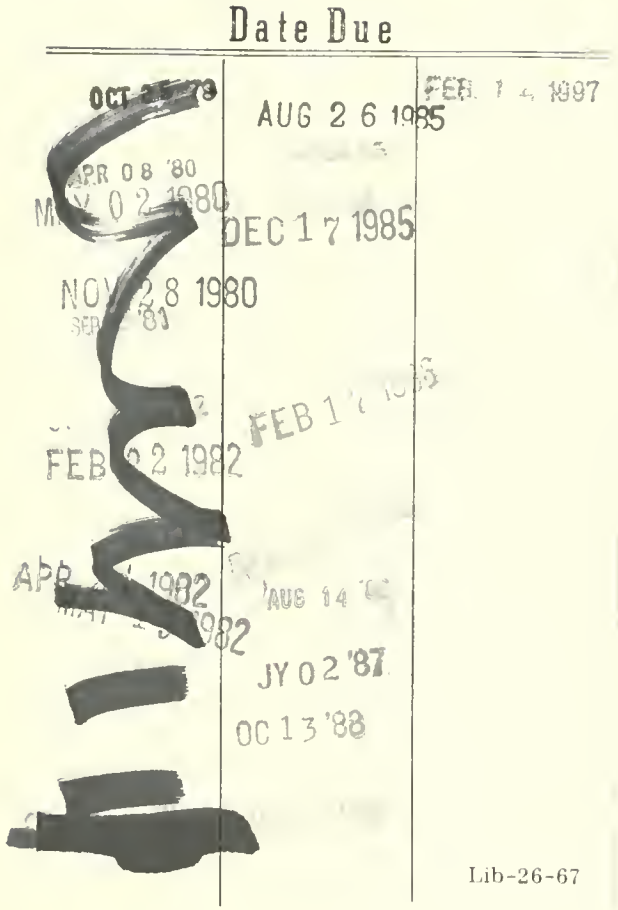
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